SMALL SATELLITE LAUNCH OPPORTUNITIES ON PSLV

By

S. Ramakrishnan, Project Director
S.V. Sharma, Deputy Project Director
L.Sowmianarayanan, Deputy Project Manager
POLAR SATELLITE LAUNCH VEHICLE PROJECT
VIKRAM SARABHAI SPACE CENTRE, ISRO
THIRUVANANTHAPURAM – 695 547, INDIA
FAX NO. 332310, 332902

0. ABSTRACT:

The Polar Satellite Launch Vehicle (PSLV) developed by the Indian Space Research Organisation (ISRO) has entered its operational phase with three successful launches, the latest being the PSLV-C1 / IRS-1D mission carried out in September 1997. In this flight, the enhanced payload capability of the vehicle viz., 1200 kg in 800 km SSPO (Sun-Synchronous Polar Orbit) has been validated and this uprated configuration will serve as the standard workhorse to orbit operational Indian Remote Sensing (IRS) satellites for the country's Earth Observation Programme.

To forge co-operation in space and provide opportunities for the countries / institutions to gain access to space and also to commercialise the spare payload capacity, certain features are built into the PSLV to carry and orbit auxiliary satellites on piggy - back mode. Two Passenger Payloads (PPL) upto a mass of 100 kg each and of size 0.6 m x 0.6 m x 0.8 m can be accommodated in PSLV along with a 1000 kg class primary satellite. PPL interfaces are defined and separation systems developed and qualified for this purpose. Expertise exists to analyse the user requirements and to evolve mission strategies for multi-satellite injection.

Second operational flight of PSLV (PSLV-C2) carries the auxiliary satellites KITSAT-3 developed by Satellite Technology Research Centre (SaTReC) of South Korea and DLR-TUBSAT developed by DLR / Technical University of Berlin. The primary satellite is Indian Remote Sensing Satellite, IRS-P4.

The paper describes PSLV configuration, provisions to accommodate auxiliary satellites, the separation system and interfaces. The paper highlights the mission studies carried out for deployment of auxiliary satellites, and system level tests conducted. The relevant pre-launch facilities available at SHAR, the launch range of ISRO, are also outlined.

1. PSLV CONFIGURATION :

The Polar Satellite Launch Vehicle (PSLV) is a four stage vehicle developed primarily to launch remote sensing satellites of 1000 kg class in polar sun-synchronous orbit. It is powered by solid propellant first and third stages and liquid propellant second and fourth stages. A 2.8 m diameter core motor and six 1.0 m diameter strapon motors (PSOM's) constitute the first stage. Four strapons are ignited on the ground while the remaining two are ignited in flight, considering the requirement of maximising payload and limiting the vehicle loads. The core motor case is made of M250 grade Maraging steel and carries 138 t. of solid propellant (HTPB). The second stage carries 40 t. of propellant (UDMH and N2O4) in an aluminium tank with a common bulkhead. A 730 kN thrust turbo pump fed Vikas engine propels the stage. The third stage using composite motor case carries 7 t. of propellant (HTPB). The fourth stage with 2 t. of propellant (MON and MMH), has two high performance pressure fed engines of 7 kN thrust, operating in tandem.

An Inertial Navigation and Guidance System (IGS) in the equipment bay guides the vehicle from lift-off to spacecraft injection. The Digital Autopilot (DAP) and Closed Loop Guidance (CLG) scheme resident in the onboard computer, ensures the required attitude manoeuvres and guided injection of the spacecraft into the specified orbit. The CLG is initiated during the second stage thrusting phase. The three axes attitude stabilisation of the vehicle is achieved by the autonomous control system provided in each stage. The first stage is equipped with Secondary Injection Thrust Vector Control (SITVC) for pitch and yaw control and for roll control two swivellable Roll Control Thrusters (RCT) are used. After the first stage burnout (during auxiliary control phase), the RCT engines are used for yaw and roll control and a set of four ON-OFF thrusters (ACS) provide pitch control. Second stage has Engine Gimbal Control system (EGC) for pitch and yaw and Hot gas Roll Control Module (HRCM) for roll control. The third stage has Flex Nozzle Control (FNC) for pitch and yaw during the thrust phase. The fourth stage is controlled during thrust phase by gimballing its two engines for pitch, yaw and roll. Reaction Control System (RCS) provided in the fourth stage provides pitch, yaw and roll control during coast phase. These thrusters also implement roll control during third stage and post cut-off manoeuvres of the fourth stage.

A bulbous aluminium alloy Heat Shield of 3.2 m diameter protects the spacecraft against hostile environment during ascent phase and is jettisoned at a minimum altitude of 105

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km using a pyrotechnic based zip cord mechanism. The strapon joints are made of ball and socket with clamps fastened through frangible nuts while spring thrusters provide the jettisoning energy. The first stage uses Flexible Linear Shaped Cord (FLSC) to sever the interstage structure and the jettisoning is achieved by retro rockets. Ullage rockets ensure positive acceleration of the vehicle during second stage (PS2) ignition to enable start up of the liquid engine. The second stage separation is based on Merman band and jettisoning is by retro rockets. The third stage separation is through ball lock mechanism and springs, while fourth stage again uses band clamp with helical compressed springs for imparting separation velocity to the satellite.

The two passenger payloads (PPL) are mounted on the vehicle Equipment bay 180 degree apart (at P+ & P-) through individual adaptors and separation systems. The passenger payloads are injected one by one after the main satellite (IRS-P4) deployment. The IRS-P4 is separated in the orbital plane. First passenger satellite KITSAT-3 is separated after a yaw manoeuvre of 40 degree and the TUBSAT after another 40 degree reorientation in the same direction. The separation systems for PPL are based on "Ball lock" mechanism and helical compressed springs impart the jettisoning velocity necessary for collision free separation. The payloads are deployed from fourth stage in three axis stabilised attitude hold mode.

The Vehicle is equipped with instrumentation to monitor system performance during flight. S-band PCM telemetry systems and C-band transponders cater to these requirements. The tracking systems provide real time information for flight safety and preliminary orbit determination. Telecommand system together with the destruct system hardware provided onboard, enables vehicle flight termination in case of unacceptable deviations in flight path.

PSLV configuration is shown in Fig.1. The current payload capability for SSPO and LEO (Low Earth Orbit) missions at various inclination are given in Fig. 2 & 3.

Presently design and development is on for creating interfaces for launching various types of multiple payloads on-board PSLV, the details of which are shown in Fig. 4. This includes (a) a Dual Launch Adaptor (DLA) for carrying two satellites of 600 to 1000 kg, (b) Satellite deck to cater to four satellites of mass up to 300 kg each and (c) a vertical dispenser for carrying three or four satellites of 300 to 400 kg each with lateral mode of separation. It is expected that these options will be available for customers by the beginning of 2001.

2. LAUNCH COMPLEX & FACILITIES

2.1 Launch Complex

The final vehicle and spacecraft preparations, integration, checkout and the launching of the vehicle are carried out at Launch Facilities in Shriharikota Range (SHAR). The SHAR complex located 80 km north east of Madras (Lat. 13.73 deg. & Long. 80.24 deg.) is ideally positioned on east coast of India. It has all the required infrastructure for the launch of space vehicles both in equatorial as well as in polar orbits. The main elements of the PSLV launch complex are the following.

- Mobile Service Tower (MST), Umbilical Tower (UT) & Launch Pedestal (LP)
- Solid Motor Preparation Facility (SMPF)
- Sub-System Preparation Facility (SSPF) for all interstages, PS2 stage and Heatshield
- Liquid Propellant Storage and Transfer Facility (LPLF)
- Hardware storage facility for interstages
- Launch Control Centre (LCC) & Mission Control Centre (MCC)
- Range Instrumentation and Support Facility (RIS)

The vehicle is vertically integrated over the launch pedestal which is located above the jet deflector and the two exhaust ducts enable smooth flow of the exhaust gases. The umbilical tower provides interface structure through which all the required fluid servicing lines and electrical checkout lines are attached to the vehicle and disconnected at lift-off. At the time of vehicle integration, the 75m tall Mobile Service Tower is positioned around the launch pedestal and the umbilical Tower to facilitate access as well as protective enclosure for the vehicle during integration. It also houses handling systems and ensures clean environment for the vehicle and satellite assembly. The tower is moved on a rail system to a safe distance of 100 m from the vehicle at the time of launch.

2.2 Spacecraft Handling & Checkout

The spacecraft is brought in a container to the launch site. Spacecraft agency makes arrangements for transportation of its necessary equipment to the launch site. At the launch site, support is provided for handling the spacecraft. The spacecraft can undergo a detailed checkout in the satellite building SP-1 before being shifted to SP-2 for propellant filling. The spacecraft is moved to the service structure at the launch pad (SP-3) around T-10 days for mating with vehicle.

2.2.1 SP-1 Facility

The spacecraft arrives at the launch site at SP-1 facility located approximately 7 km from launch pad and close to the Mission Control Centre (MCC). Fig. 5 gives the layout of the SP-1 facility. This facility is primarily for carrying out checks on the Satellite. Preparation of the spacecraft for launch is carried out at this facility after checkout. SP-1 has a 100000 class clean room of dimensions 17 m x 15

m x 8 m. There is a satellite checkout bay area 12 m x 6 m located adjacent to the clean room

Single phase 230 V and 3 phase 440 V / 50 Hz supply with number of outlets are provided. Small fitting shop, an electronics laboratory and a conference room are also provided. A sheltered area of 300 sq.m. adjacent to this building is available to unload the satellite and its equipment immediately on arrival at the site.

2.2.2 SP-2 Facility

SP-2 facility is designed primarily for propellant filling and pressurisation operations. This facility includes a clean room with inter-lock arrangements for material entry. Size, cleanliness, temperature and humidity control are same as those in SP-1 facility.

The clean room of 6 m x 4 m has propellant loading area with breathing air outlets at appropriate intervals around the filling area. An emergency exit with an adjoining personnel shower are also in SP-2. To facilitate satellite checkout during and after the filling operations, a room of dimensions 6 m x 8 m for installation of checkout equipment is also identified. Fig. 6 gives the layout of the SP-2 facility.

2.2.3 SP-3 Facility

From the SP-2 facility, the satellite is moved to SP-3 facility, at the top of the Mobile Service Tower (MST) for integrating it to the launch vehicle. The SP-3 is located approximately at 41 m level of MST. It has provision for storing an empty transportation container, and has a personnel entry airlock. The specifications for the SP-3 facility, except for the area, are same as those for the SP-1 and the SP-2. The launch vehicle and main spacecraft interface height above the SP-3 platform level is approximately 3.6 meters and for PPL spacecraft is 2.2 meters. Suitable provisions are made to get a close access to the satellite as well as the satellite - vehicle interface. SP3 layout is given in Fig. 7 and location in the MST is shown in Fig. 8.

3. PSLV-C2 MISSION WITH PPLs

3.1 Flight Sequence

Fig.9 provides the PSLV-C2 flight sequence and flight parameters for nominal vehicle performance up to guidance cut-off. Fig. 10 depicts multiple satellite separation and manoeuvre sequences planned for PSLV-C2 mission with IRS-P4 as primary satellite and KITSAT/TUBSAT as passenger payloads.

3.2 Re-orientation manoeuvre Angle for Multiple Satellite Separation

In PSLV-C2 flight fourth stage thrust termination is by guidance cut-off. This event is represented as "RTD T6". After this event, vehicle attitudes are controlled by using six numbers of 50N thrusters (RCS - Reaction Control System) located on IS 3/4 propulsion Bay Structure. For the re-orientation manoeuvre phases, the control forces from RCS are adequate for the rotation and attitude hold mode operations. These are ensured from the controllability study results. The IRS-P4 spacecraft will be separated with 0.8m/s as relative velocity at T6+27s (ie 27s after occurrence of "RTD T6"). After 10s, ie T6+37s, re-orientation of PS4 stage along with KITSAT and TUBSAT satellite will commence with yaw rate of -1.33 deg/s for 30 sec (ie. up to T6+67 s). After this manoeuvre, PS4 stage will be in active attitude hold mode for 10 s (ie. up to T6+77 s). At this stage, PS4 stage orientation will be 40 deg in negative yaw direction w.r.t IRS-P4 spacecraft. At T6+77 s KITSAT satellite will be separated with 1.0 m/s relative velocity. Second re-orientation manoeuvre in yaw for PS4 stage along with TUBSAT will take place from T6+87 s to T6+117s with the yaw rate of -1.33 deg/s. At the end of T6+117s, the PS4 stage will be -80 deg in yaw w.r.t IRS-P4 Spacecraft. From T6+117 s to T6+127s, PS4 stage will be in active attitude control mode at the same orientation angle. At T6+127s, TUBSAT will be separated from PS4 stage with the relative velocity of 1.0 m/s. After 10 s from TUBSAT separation event, (ie. at T6+137 s) re-orientation of spent PS4 stage will commence at the rate of 1.33 deg/s for about 30s (ie. up to T6+167 s). After that up to T6+400 s, spent PS4 stage will be in active attitude hold mode to facilitate tracking for Preliminary Orbit Determination purpose.

The above sequence of separation and re-orientation manoeuvre is shown in Fig. 10.

4. PPL INTERFACES TO VEHICLE

4.1 Mounting Configurations

The mounting configuration of the satellites in PSLV payload envelope is as shown in Fig. 11. The IRS-P4 spacecraft is mounted on the composite Payload Adaptor (PLA) as shown in Fig. 11. For mounting the small satellites, EB deck plate is redesigned and the two 40 deg. sectors of the EB deck plate at P+ and P- are identified as PPL decks. PS4 stage and redesigned EB have been qualified for static as well as dynamic loads through structural model tests.

4.2 IRS-P4 Separation System

The Separation System for IRS-P4 is based on `band-clamp' system. Redundant bolt cutters sever the bolts and band is released. There are four spring thrusters provided to impart a jettisoning velocity of approximately 0.8 m/s to the IRS-P4 Satellite relative to PS4 stage.

4.3 KITSAT-3 Separation System

KITSAT-3 is mounted on the EB deck plate at P+ axis with an offset of 1020 mm from vehicle axis and with a tilt

of 5 deg with the vehicle axis. This tilt is introduced in the interface adaptor which is provided below the separation system. The separation system is also tilted through the same angle of 5 deg, so that the springs are exerting the force along the axis of the satellite. The separation system is based on "Ball Lock" mechanisms and has a mounting diameter of 358 mm. Redundant pyro thrusters rotate the retainer ring and cause the release of the ball lock. There are 10 sets of matched springs designed to provide a jettisoning velocity of approximately 1 m/s with respect to PS4 stage. The gaps and controlling dimensions for the KITSAT mounting is shown in Fig 12. The configuration of the separation system is shown in Fig 14. There is one separation plane connector provided at the base of the satellite.

4.4 DLR-TUBSAT Separation System

DLR-TUBSAT is mounted on EB deck plate at P- axis with an offset of 1020 mm from vehicle axis and with a tilt of 4 deg introduced through the interface adaptor which is provided below the separation system. The separation system is similar to KITSAT separation system, based on "Ball Lock" mechanisms and has a mounting diameter of 238 mm. Redundant pyro thrusters rotate the retainer ring and cause the release of the ball lock. There are 4 sets of matched spring designed to provide a jettisoning velocity of approximately 1 m/s with respect to PS4 stage. The gaps and controlling dimensions for the TUBSAT mounting is shown in Fig 13.

5. LOADS AND ENVIRONMENTAL TEST LEVELS ON PPLs

5.1 Quasi Steady State Loads (QSL) and Sine Vibration Test Levels

Steady state and low frequency dynamic accelerations in each stage are worked out based on analytical / flight data analysis. These details are given in Table-1 for dimensioning purpose.

Table-1

Maximum Vehicle Acceleration Levels

Stage	Lateral Acceleration (g)		Longitudinal Acceleration (g)	
	Steady	Dynamic	Steady	Dynamic
I	0.50	0.50	5.00	1.00
II	0.60	0.50	4.5 (2.0*)	0.5 (4.2*)
III	0.60	0.50	6.20	0.20
IV	0.30	0.50	1.00	0.20

* Response due to N2O4 depletion

Mathematical model of PSLV fourth stage (PS4) along with changes due to PPL's mounting have been validated by vibration test/analysis. Coupled Load Analysis (CLA) using PSLV mathematical model and modal model of IRS-P4, KITSAT and TUBSAT has been carried out. Critical conditions considered are i) Second stage cut-off event using engine transients measured in D2 flight ii) Maximum dynamic pressure (Qmax) event in first stage using tuned gust of 9 m/s. PPL acceptance Sine test levels worked out are based on CLA and details are given in Table-2.

Table – 2

FAT Sine levels based on CLA

LONGITUDINAL		LATERAL	
Frequency (Hz)	Level	Frequency (Hz)	Level
5-11.5	4.5 mm DA	5-7	4.5 mm DA
11.5-25	1.2 g	7-30	0.45 g
25-33	2.5 g	30-100	0.3 g
33-60	2.5-0.5 g		
60-100	0.5 g		

5.2 Random Vibration Levels

Vibration test levels at payload interface / EB deck plate are derived from measurements in four PSLV-flights. Considering flight experience, the Flight Acceptance Test (FAT) random vibration levels are defined as given in Table-3.

Table – 3

FAT Random vibration Levels

Frequency	PSD (g^2/Hz)	grms	Duration (s)	Axis
20	0.001	4.47	60	All Three axes
110	0.001			
250	0.015			
1000	0.015			
2000	0.004			

5.3 Shock Levels

Shocks at payload interface and VEB due to first stage, second stage, third stage and heat shield separation are measured in four flights. Separation shock at KITSAT/TUBSAT interface are measured during their separation tests on structural model conducted for C2 Configuration. Shock Response Spectrum (SRS) envelope of flight / ground test measured shock spectrum for PPL is given in Fig. 15.

6. SEPARATION DYNAMIC ANALYSIS

Short period dynamic studies are carried out considering spent fourth stage residual rate, mass, moment of inertia, CG offsets, spring stiffness and stroke dispersions. The separation process is collision free ensuring minimum lateral gap of 25 mm between PS4 & KITSAT and 124 mm between PS4 & TUBSAT based on initial lateral gaps of 97.6 mm and 170 mm respectively.

7. RELATIVE MOTION OF MULTIPLE SATELLITES AND SPENT PS4 STAGE (LONG TERM ORBIT PROPAGATION RESULTS)

A study is carried out to assess the possibility of collision between any two of the three satellites (IRS-P4, KITSAT and TUBSAT) as well as spent PS4 stage in the PSLV-C2 mission. This is essentially a long period orbit evolution study involving four bodies, namely IRS-P4, KITSAT-3, DLR-TUBSAT and spent PS4 stage.

TABLE-5

Relative distances Between Bodies

Bodies	After 100m. (1 Revols) (km)	After 16.75 hrs. (10 Revols) (km)	After 1 Month (km)	After 3 Months (km)
PS4 - IRS	15.7	157.6	6609.8	14100.1
PS4 – KIT	12.7	127.8	5434.1	13120.2
PS4 – TUB	4.3	43.0	1873.5	5486.5
IRS – KIT	2.9	30.1	1297.2	3856.2
IRS – TUB	11.4	115.5	4893.9	12366.2
KIT - TUB	8.4	85.4	3655.5	10006.3

Results of the analysis

- Long term growth of the relative distances is provided in Table-5.
- Fig. 16, 17 and 18 depict the growth of relative distances for 300 s, 6000 s (one revolution) and 90 days respectively.
- There is no collision possibility for the present sequence and separation velocities over three months duration.
- KITSAT / TUBSAT Satellite Separation Velocities will be firmed up after dispersion studies.

8. CONCLUSIONS

The three succcessive successful PSLV flights have validated the maturity of vehicle systems and launch operations as well as the robustness of the launcher. The PSLV upper stage is reconfigured for C2 mission, to carry two 100 kg class passenger payloads on equipment bay deck. An elegant low shock separation system for the deployment of small satellites has been developed and qualified. The passenger payload slots in PSLV will be a standard feature in the forthcoming flights, to provide launch opportunities for small satellite community. Reconfiguring of upper stage and payload interface developement for mounting multiple satellites is in progress. Possibilities of launching multiple satellites on dedicated PSLV missions also exist.

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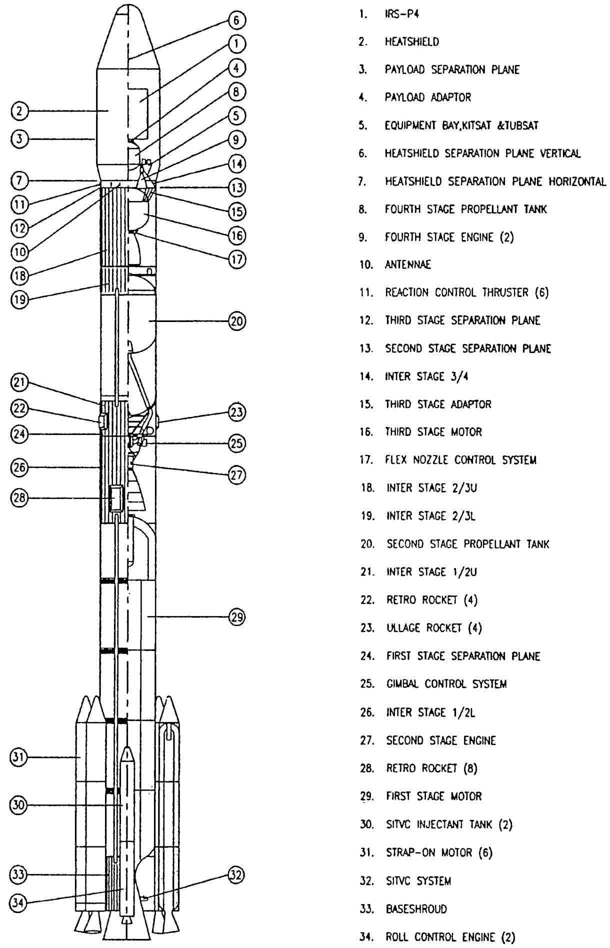

Fig.1 PSLV VEHICLE CONFIGURATION

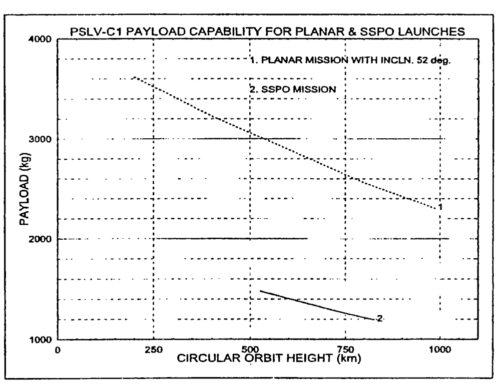

Fig. 2 PSLV PAYLOAD CAPABILITY FOR SSPO MISSION

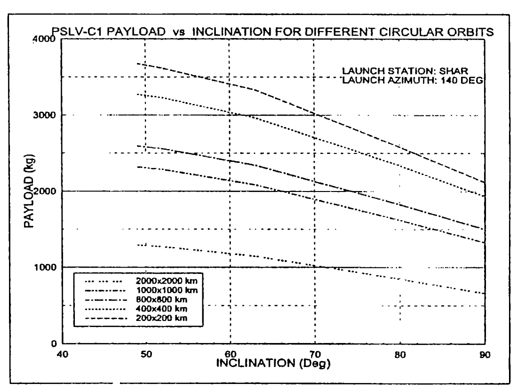

Fig. 3 PSLV PAYLOAD CAPABILITY FOR LEO MISSION

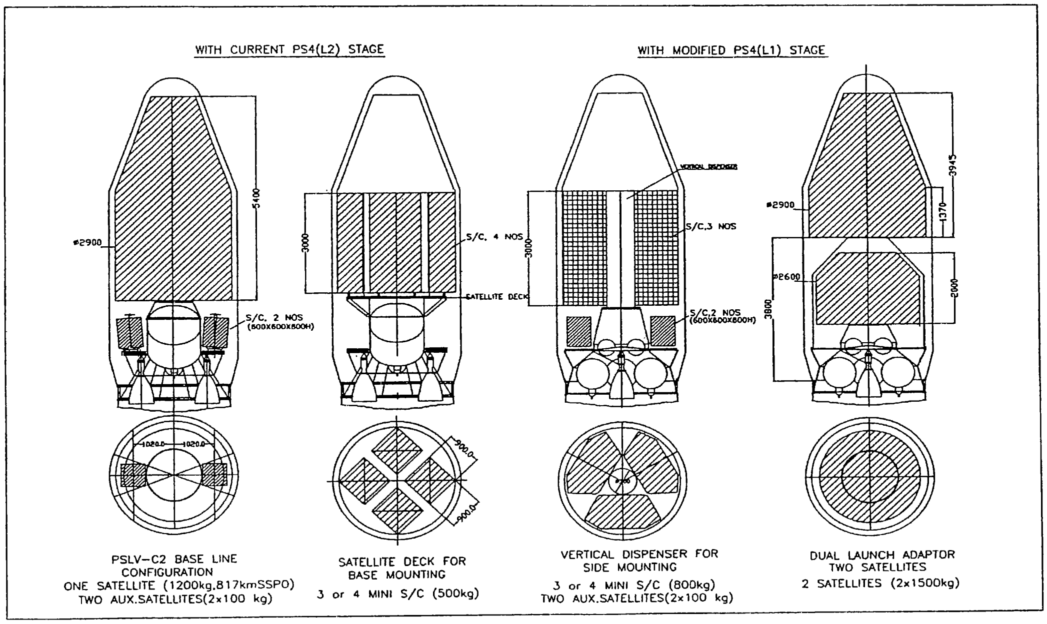

Fig. 4 PSLV PAYLOAD ENVELOPE CONFIGURATION OPTIONS

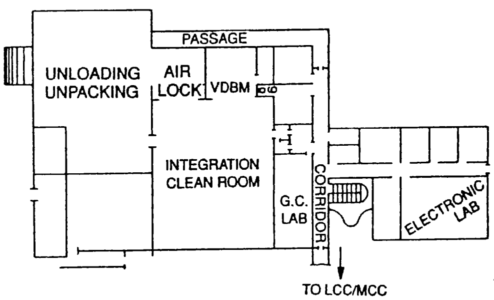

Fig. 5 LAYOUT OF SP-1 FACILITY

1. HIGH BAY
2. MATERIAL AIR LOCK
3. CLEAN ROOM
4. CHANGE ROOM
5. SAFETY CONTROL ROOM
6. ELECTRONICS LAB
7. CHECKOUT TERMINAL
8. AIR LOCK
9. BOOSER PUMP ROOM
10. OBSERVATION ROOM
11. ELEC. ROOM
12. AIR SHOWER

SP-2 FACILITY (2,3,4,5,6 & 12)

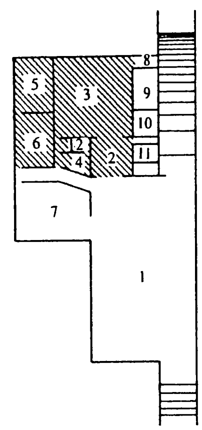

Fig. 6 LAYOUT OF SP-2 FACILITY

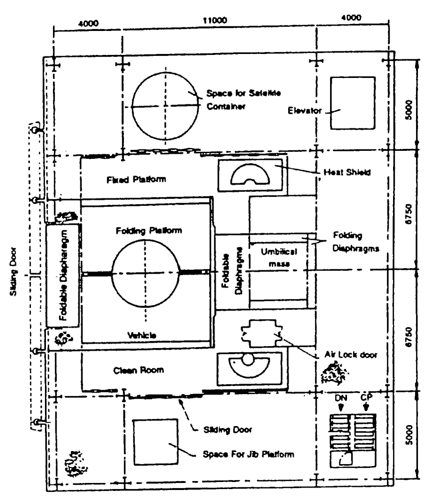

Fig. 7 LAYOUT OF SP3 FACILITY

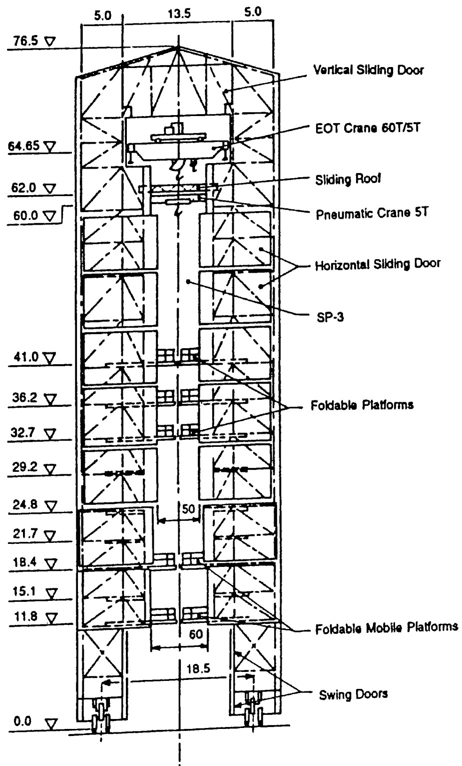

Fig. 8 LOCATION OF SP3 FACILITY IN MST

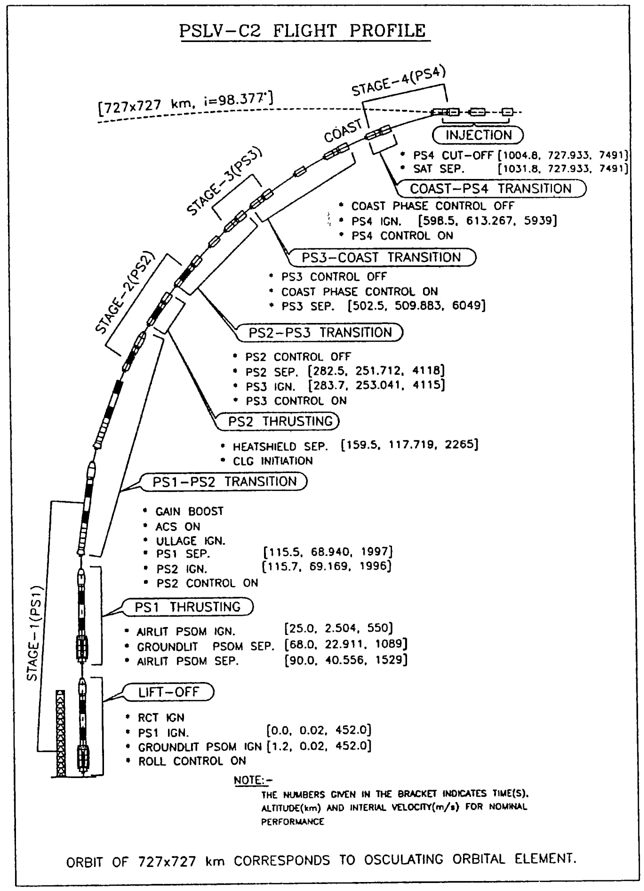

Fig. 9 PSLV – FLIGHT PROFILE UPTO IRS-P4 INJECTION

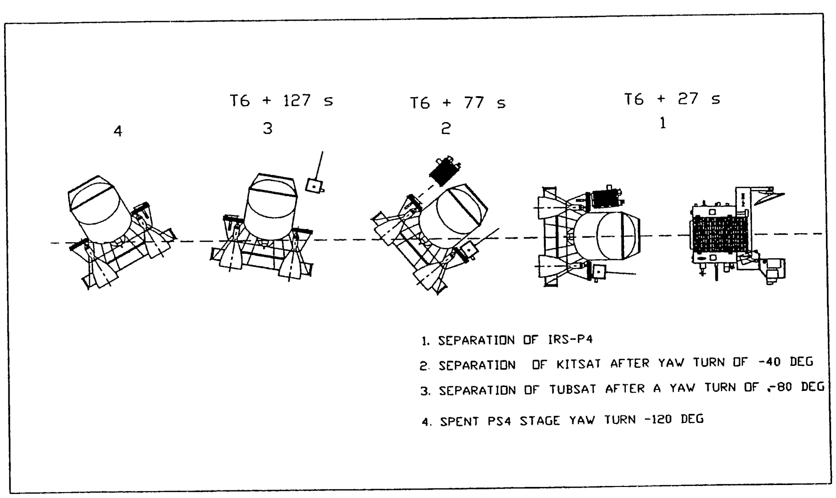

Fig.10 SEPARATION SEQUENCE OF SPACECRAFTS IN PSLV-C2 MISSION

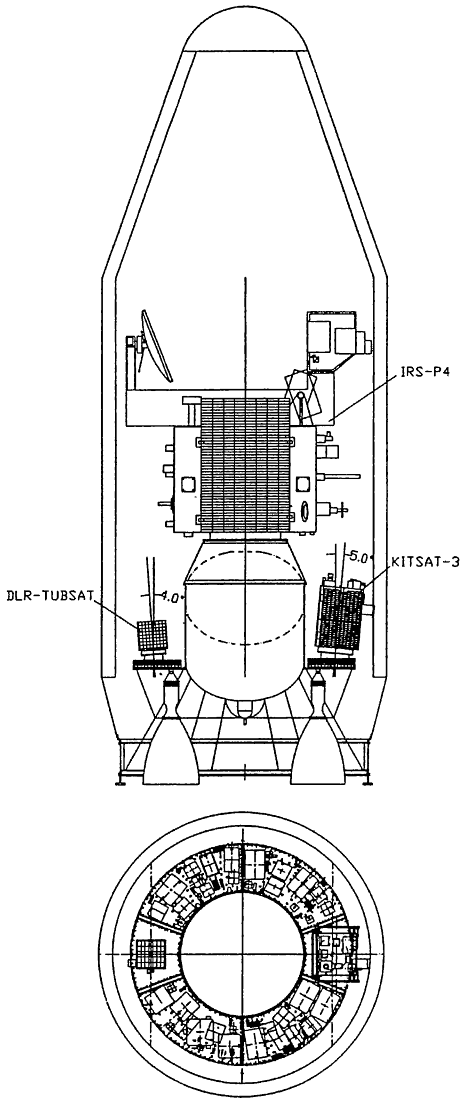

Fig. 11 IRS-P4, KITSAT & TUBSAT IN PSLV-C2 ENVELOPE

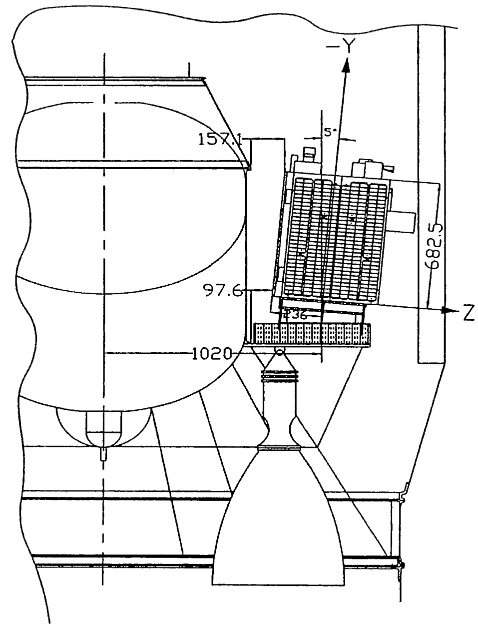

Fig. 12 KITSAT MOUNTING SCHEME

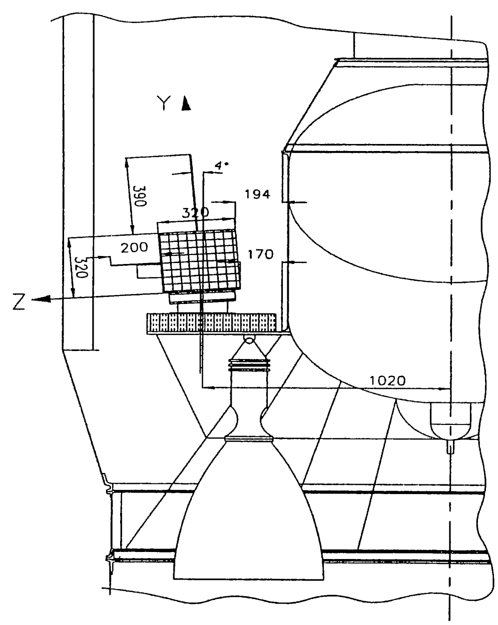

Fig. 13 TUBSAT MOUNTING SCHEME

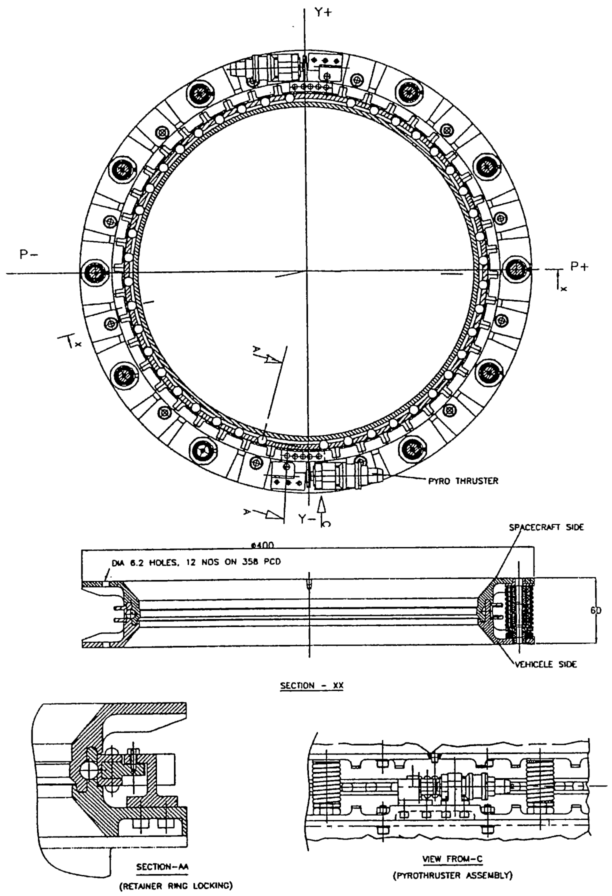

Fig. 14 SEPARATION SYSTEM CONFIGURATION FOR KITSAT

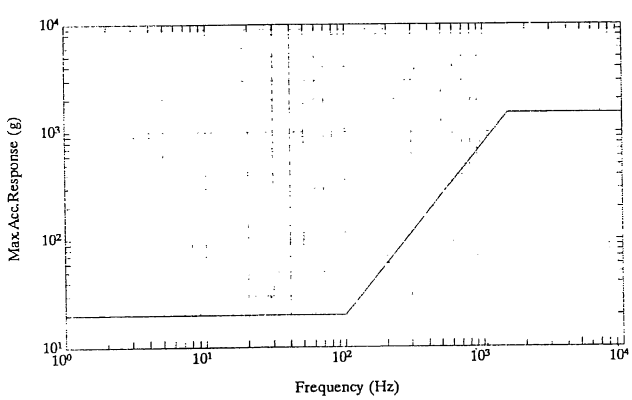

Fig. 15 SRS ENVELOPE FOR PPL's

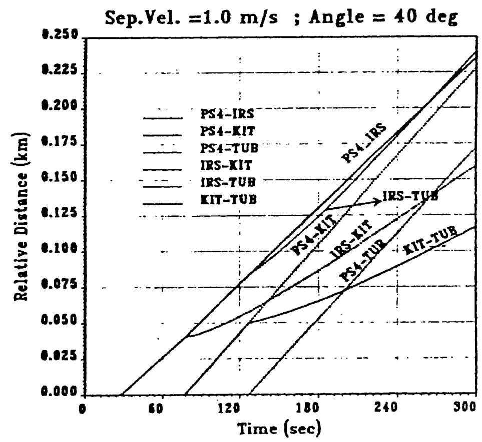

Fig. 16 GROWTH OF RELATIVE DISTANCES FOR FIRST 300 s

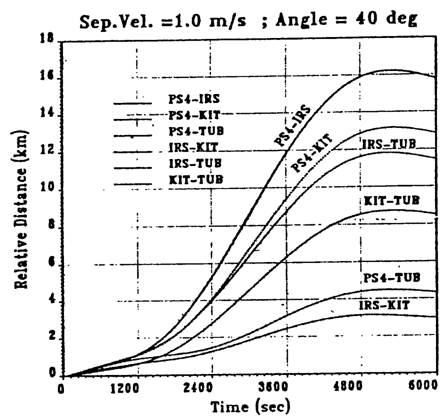

Fig. 17 GROWTH OF RELATIVE DISTANCES FOR FIRST 6000 s

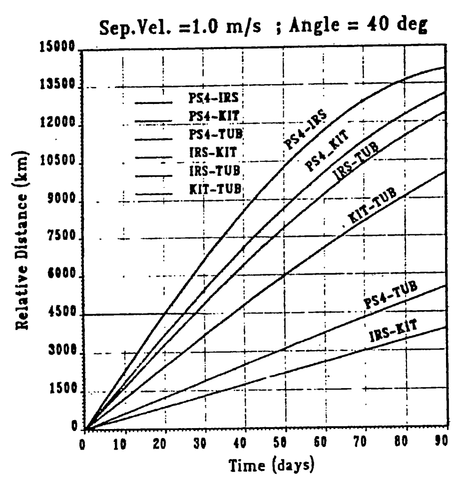

Fig. 18 GROWTH OF RELATIVE DISTANCES FOR FIRST 90 DAYS

Technology

Chair :

Denis Borel, ***CNES***